

MESA Learning Microsystems Series



Overview of Micro-Technologies and Micro-Systems

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Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under contract DE-AC04-94AL85000.



Outline

- Historical perspective
- What makes semiconductors special?
- Microelectronics: transistors & integrated circuits
- Optoelectronics
- Micromachines (MEMS*)
- Microsensors
- Microsystems

* MEMS = Micro Electro Mechanical System



Waves of Technical Revolutions: Electricity

1850 1900 1950 2000 2050

Electricity



Edison's Light Bulb



Bell's Telephone

3



Waves of Technical Revolutions: Macroscopic Electronics (Vacuum Tubes)

1850 1900 1950 2000 2050

Macroscopic
Electronics



DeForest's Vacuum
Tube



Radio



World War II Radar

4



Waves of Technical Revolutions: Microelectronics / Transistor

1850 1900 1950 2000 2050

Transistor



First Transistor
Bell Labs



Transistor Radio

5



Waves of Technical Revolutions: Microelectronics / Integrated Circuits

1850 1900 1950 2000 2050

Microelectronics
Integrated Circuits



First Integrated
Circuit, TI



Original
IBM PC



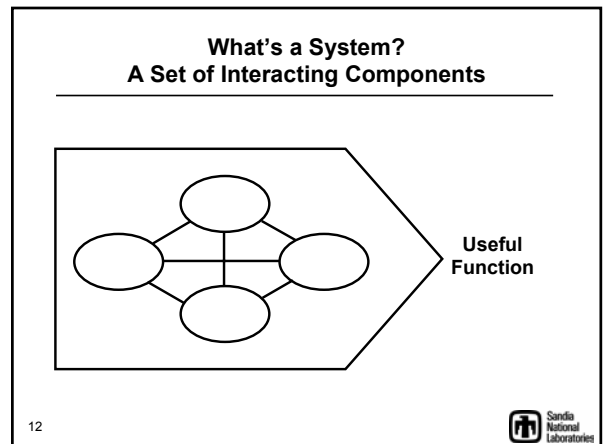
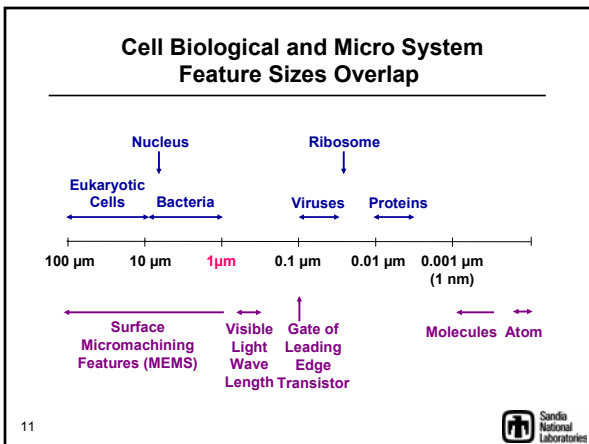
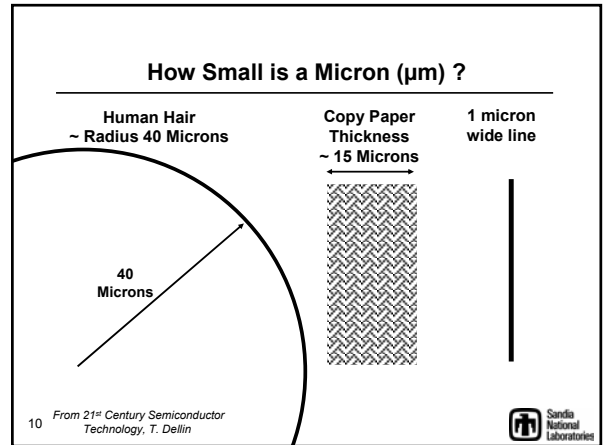
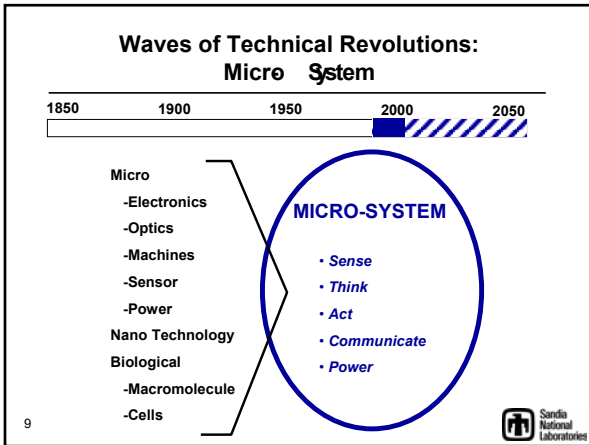
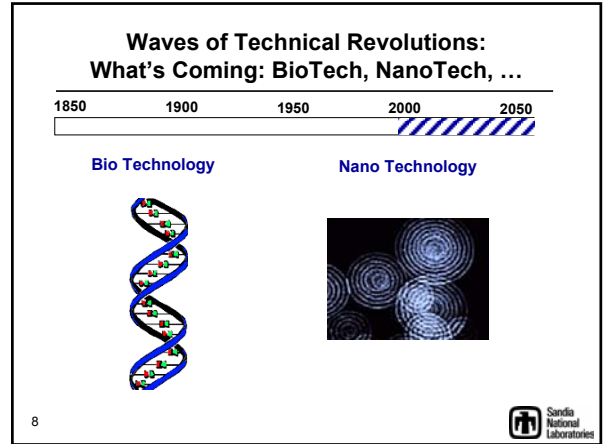
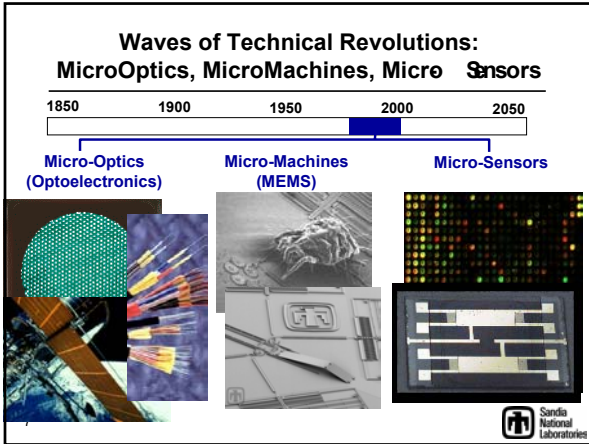
Cardiac
Pacemaker



Cell
Phone

6





What's So Special About Micro Technologies and Micro Systems?

- *Microsystems are not the best choice for every application*
- When Micro-Systems are the best choice it is because they do one or more of the following
 - Significantly reduce volume, weight and power
 - Significantly reduce cost
 - Significantly improve reliability
 - Perform functions that are not possible with macro-systems

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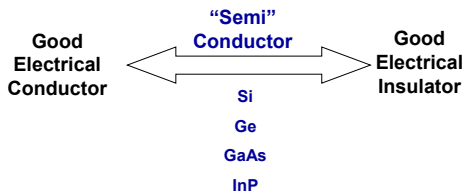
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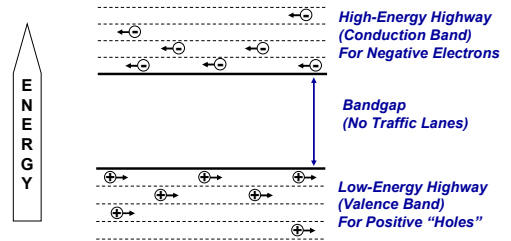
What Is a Semiconductor?



15



Semiconductors Can Conduct Current Using Two Carriers & Two Highways

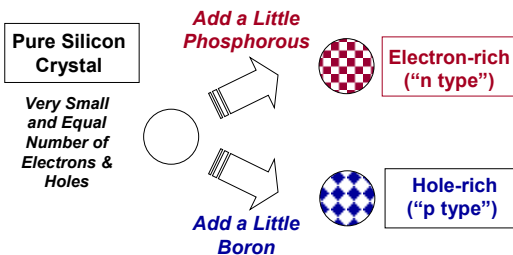


From 21st Century Semiconductor Technology Handbook, T. Dellin

16



Semiconductor "Alchemy": Adding Trace Impurities Makes Large Change in Electrical Properties



From 21st Century Semiconductor Technology Handbook, T. Dellin

17



A "Junction" Is Formed Whenever Two Different Semiconductors Are Formed



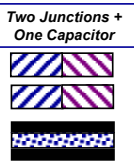
- Only allows large currents to flow from "p" to "n" but not in the opposite direction ("diode")
- Turn light into electricity
- Emit light (many, but not all, semiconductors)

From 21st Century Semiconductor Technology Handbook, T. Dellin

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The Junction Is The Basic Building Block of Micro and Opto Electronics



- Diode
- Light Emitter
- Photodetector or Solar Cell



- Better Light Emitter
- Bipolar Transistor



- MOS Transistor for high density integrated circuits

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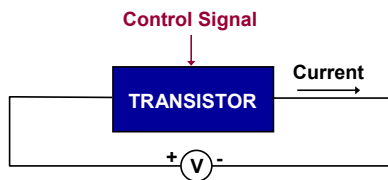
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A Transistor Is a Controllable Current Source

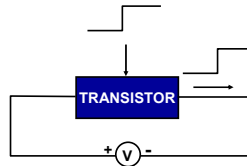


21 From 21st Century Semiconductor Technology Handbook, T. Dellin



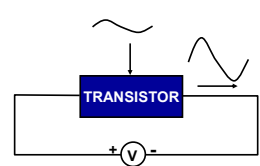
Two Main Uses of Transistors: Switches and Amplifiers

Switch
(Digital Electronics)



E.g., Microprocessor, Memory

Amplifier
(Analog Electronics)



E.g., Sensor, Radio

22 From 21st Century Semiconductor Technology Handbook, T. Dellin



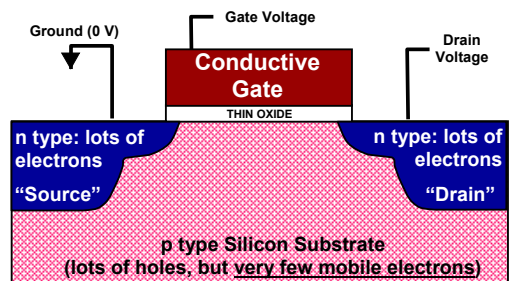
There Are Many Types of Transistors: MOS Dominates High Density ICs

- There are many types of transistors, each with strengths and weaknesses
- The MOS ("Metal Oxide Semiconductor") dominates high density integrated circuits (IC)
 - CMOS (Complimentary MOS) refers to building an IC with two types of MOS transistors
 - Silicon is the only material for high density ICs because it's the only semiconductor with the high quality oxide required for MOS

23 From 21st Century Semiconductor Technology Handbook, T. Dellin



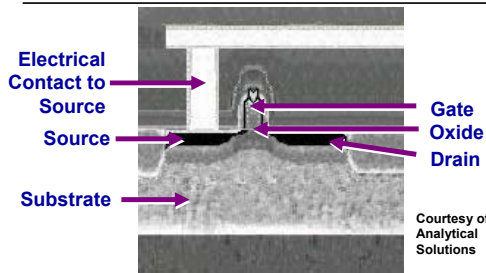
In This Module We Will Consider The n Channel Transistor



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Highly Magnified Cross Section of a Modern Transistor

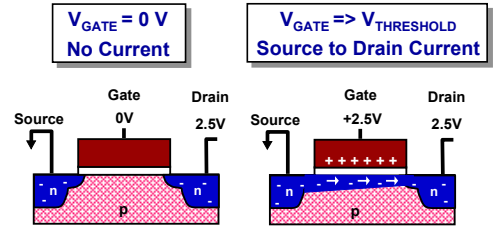


Note that gate oxide is too thin to be seen and electrical contact to gate and drain not shown

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How The n Channel MOS Transistor Works As a Voltage Controlled Current Switch

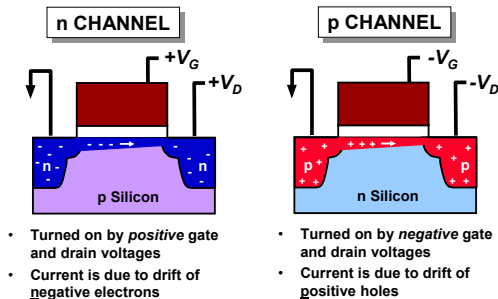


No current until the voltage on the gate is greater than threshold

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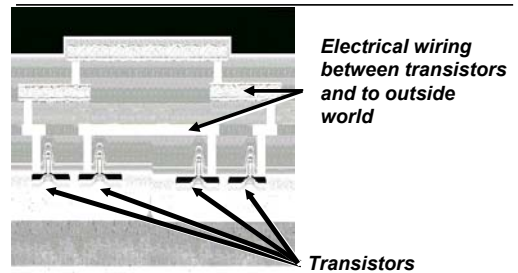
There Are Two Complementary Types of Transistors: n Channel and p-Channel



27 From 21st Century Semiconductor Technology Handbook, T. Dellin



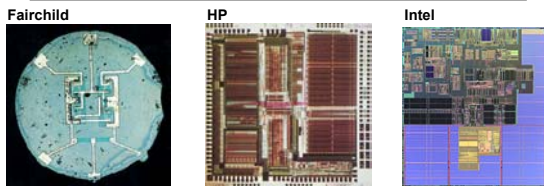
An Integrated Circuit (IC) Contains A Lot of Transistors Electrically Connected Together



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Integrated Circuit: Multiple Transistors Connected Together On a Single Chip



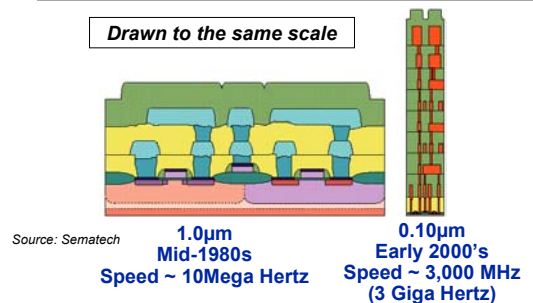
1961 – 4 Transistors 1981 ~ 1/2 Million 2002 ~ 400 Million

"Moore's Law"
Transistors Per IC Exponentially Increases

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Scaling Down Results In Faster, Better and Cheaper Transistors



Source: Sematech

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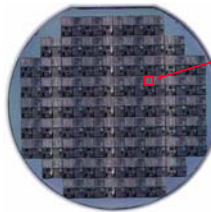
To Build An Integrated Circuit Requires An Ultra Clean, High Precision Factory



31 From 21st Century Semiconductor Technology Handbook, T. Dellin



Many Integrated Circuits Are Produced On a Single Silicon Wafer

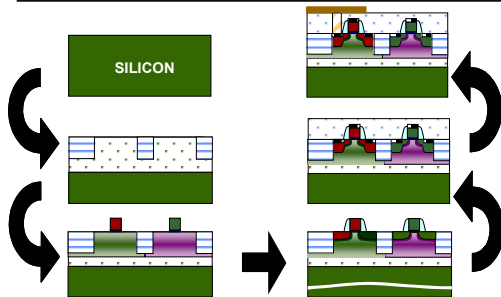


- ICs are made in a “fab”
- Each rectangle on a wafer is a separate IC
- Many wafers are processed together in a “lot”
- At the end of processing the wafers are tested and cut apart and the good ICs are put in packages
- Leads to high volume, high quality, low cost integrated circuits

32 From 21st Century Semiconductor Technology Handbook, T. Dellin



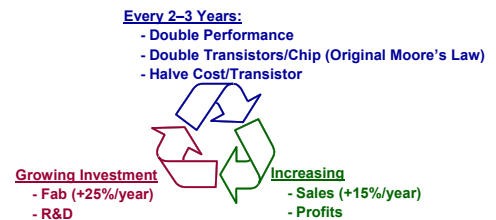
Complex Integrated Circuits Are Built Up One Feature At A Time



33 From 21st Century Semiconductor Technology Handbook, T. Dellin



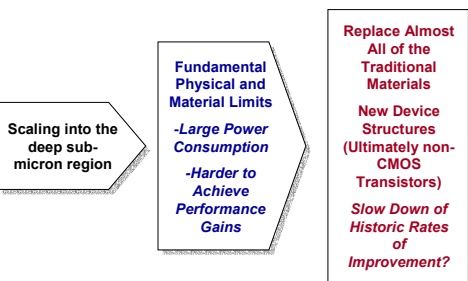
Moore's Law Cycle



34 From 21st Century Semiconductor Technology Handbook, T. Dellin



Reinventing CMOS To Sustain The Moore's Law Cycle



35 From 21st Century Semiconductor Technology Handbook, T. Dellin



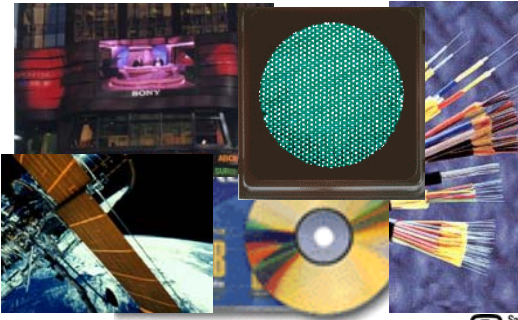
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- Microsystems

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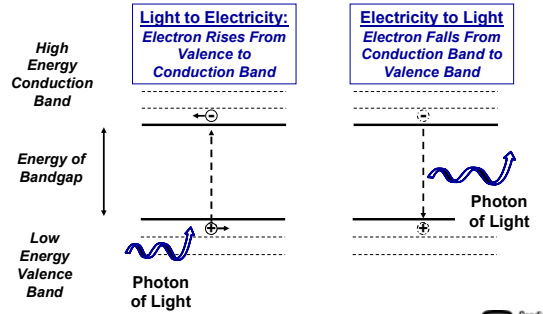
Applications of Optoelectronics



37



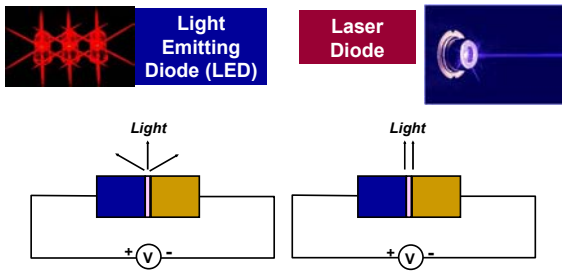
Light to Electricity and Vice Versa Results from Electrons Moving Between Bands



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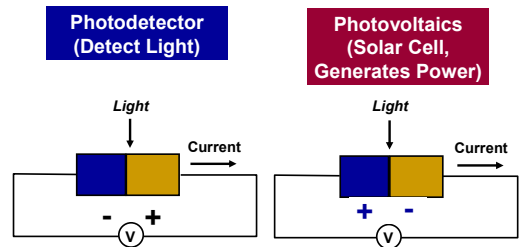
Turning Current Into Light: LED and Laser Diode



39



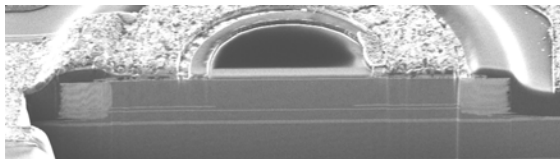
Turning Light Into Current: Photodetector and Photovoltaics



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Optoelectronics Involves A Wider Range of Semiconductors Than Microelectronics

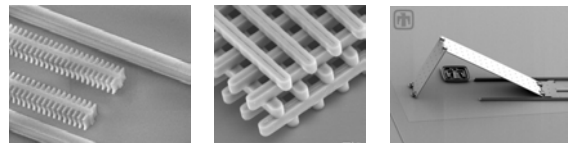


- Almost all integrated circuits use silicon
- Optoelectronics involves many semiconductors
 - Have to match the semiconductor to the wavelength ("colors") of light required
 - Have to grow precise, perfect stacks of different semiconductor crystals

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Microstructures For Guiding Light



Grated Assisted
Direction Coupler

Photonic Lattice

MEMS Movable
Mirror

We can make *photonic* integrated circuits.

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Sandia Images



Outline

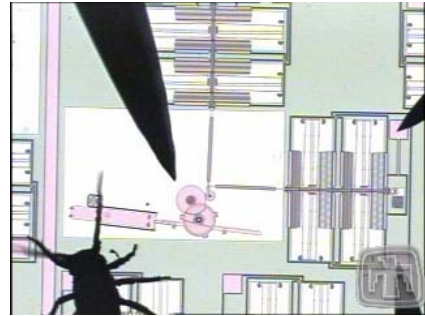
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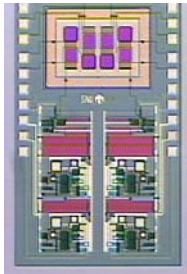
Micro Electro Mechanical System (MEMS)



44

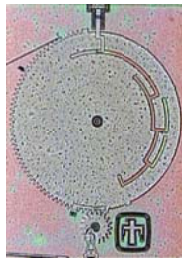


MEMS Technologies Allow Two Primary Functions: Sensing and Actuation



Sensors: Learn something about the environment

Actuators: Change something about the environment



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I. Bulk Micromachining: "How To Carve Mount Rushmore"



1. Start with a big block
2. Remove everything that doesn't look like a president

46

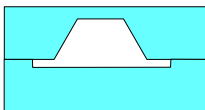


Bulk Micromachining: Etching and Wafer Bonding

Etching Features Into a Substrate



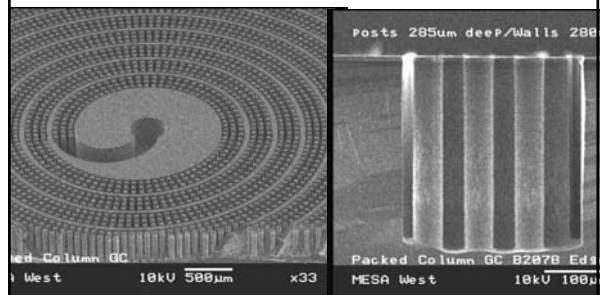
(optional) Bond Wafers Together



47



Packed Gas Chromatography Column Defined by Bulk Micromachining



48



II. Surface Micromachining: “How To Build a Keystone Bridge”

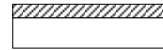


1. Build a sacrificial layer (wood beams)
2. Place the stones on top of the sacrificial layer
3. Remove the sacrificial layer

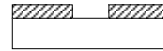
49



Surface Micromachining: Mechanical & Sacrificial Layers



Deposit sacrificial layer (e.g., oxide)



Pattern sacrificial layer



Deposit mechanical layer (e.g., polysilicon)



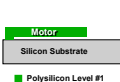
Selective release etch to remove sacrificial layer and “free” mechanical layer

50



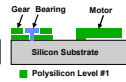
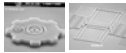
The More Mechanical Levels The More Sophisticated The Device

2-Level



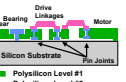
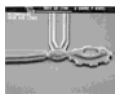
Sensors

3-Level



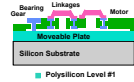
Advanced Sensors
Simple Actuators

4-Level



Advanced Actuators

5-Level

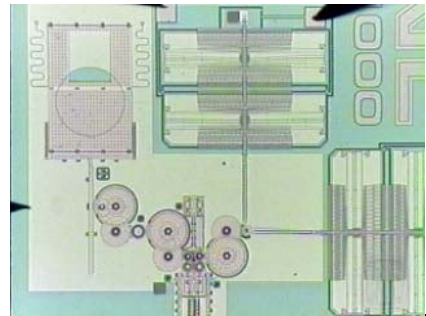


Complex Systems

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Complex Microsystems Can Be Built Using Multi-Level Surface Micromachining



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III. LIGA Micromachining: “How To Make Lots of Plastic Toy Soldiers”



1. Make a mold
2. Make soldiers by injection molding
3. Reuse mold

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LIGA Can Form “Tall” Miniature Parts

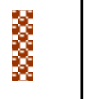
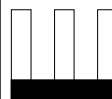
Uses X-Rays
To Form Mold
With “Tall”
Features

Electroplate
Metal Like
Nickel

Miniature
Metal Part

Metal Part Is
Reusable
Mold for
Plastics or
Ceramics

Lots of
Plastic
or
Ceramic
Parts

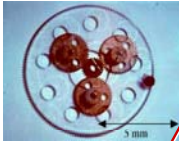


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LIGA Examples

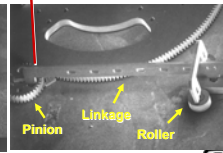
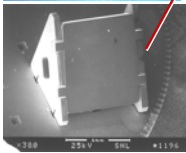
6:1 Planetary
Geared
Transmission
(Used on 8
mm diameter
motor)



MILLIENGINE ROTARY ACTUATOR



45° Mirror
Assembled
on large
gear



Pinion
Linkage
Roller

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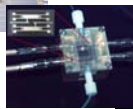
There Are Lots of Things to Sense; There Are Lots of Sensors



Physical State
Sensing



Chemical
Sensing



Biological
Sensing



Radiological
Sensing

57



“Smart” Sensors All Work In Basically The Same Way

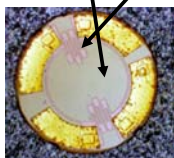
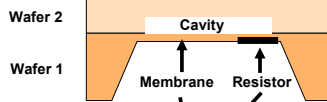
- Use a physical property that can produce an electrical signal
 - e.g., current flowing in a wire or a transistor
 - e.g., vibrations along a solid surface
 - e.g., movement of a microscopic rod of material
- Find a way to have the thing we want to sense change that physical property and, thus, change the electrical signal
 - e.g., Hydrogen can change the current flowing in a transistor
- Design an circuit that can detect the change in the electrical signal when what we want to detect is present



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Micromachined Pressure Sensor

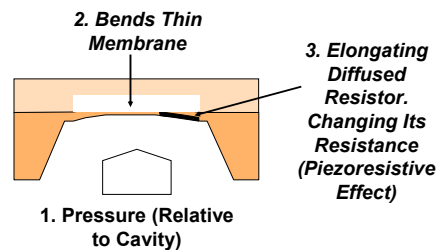


Motorola

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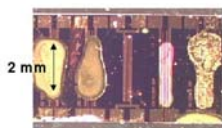
Operation of Bulk MEMS Pressure Sensor



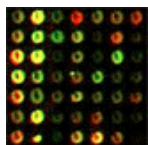
60



Chemical and Biological Sensing Using Selectively Absorbing Layers



Multiple Coating Chemical Sensor



Gene Array for DNA

- Chemical detection: use polymer layers
- Protein detection: use antibody layers
- DNA: use single strand of complementary DNA

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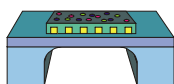
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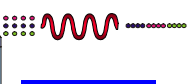
62



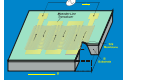
μ ChemLab™ Chemical Analysis on a Chip



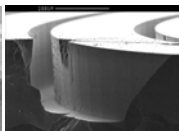
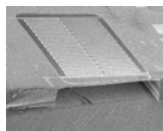
Preconcentrator
accumulates
species of interest



Gas
Chromatograph
separates
species in time



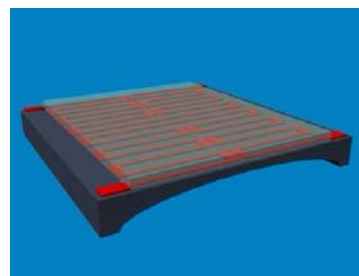
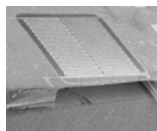
Acoustic Sensors
provide sensitive
detection



63



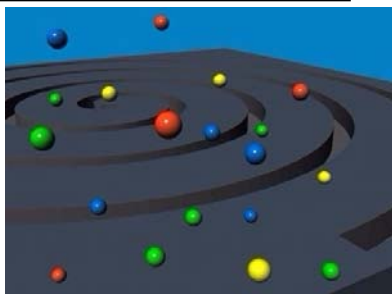
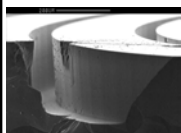
Preconcentrator Concentrates Trace Chemicals in Air



64



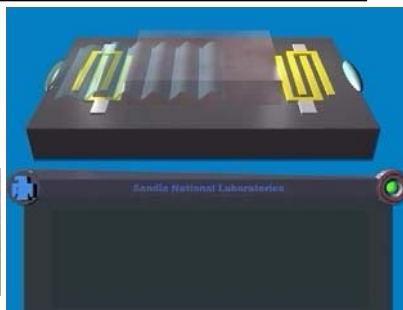
Separation Column, A Long Spiral Groove, Separates Different Chemical Species



65



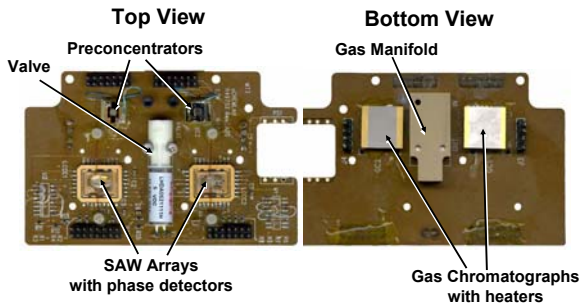
Detectors Measure The Time and Quantity of Chemicals Leaving the Separation Spiral



66



Putting It All Together: Hybrid Integration



67



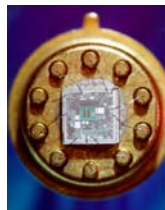
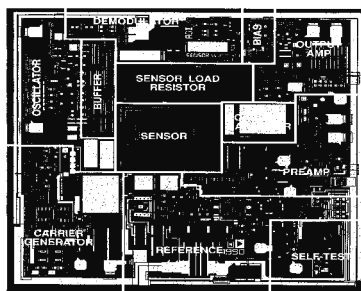
Putting It All Together: Monolithic Integration



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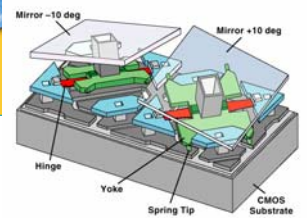
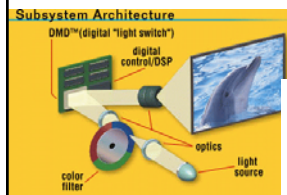
Analog Devices Air Bag Accelerometer: MEMS + CMOS



Analog Devices Accelerometer



Texas Instruments Digital Mirror Device™ MEMS + CMOS



Images provided by Texas Instruments
(<http://www.ti.com/dlp/docs/developer/reliability/>)

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To Boldly Go Where People Cannot Easily Go

Micro-Robot



Sandia

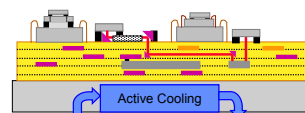
Camera in a Pill To Image the Intestine



Given Imaging



Advanced 3D Packaging Is a Key Enabler of Microsystems

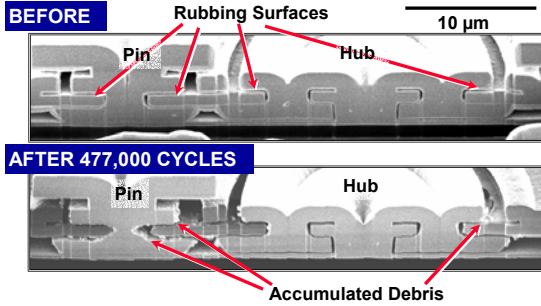


- Want to assemble microsystems in the smallest possible volume
- Challenges to 3-d packaging include
 - Yield
 - Test/Failure Analysis
 - Power Dissipation

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Science based Reliability Is a Key Enabler of Microsystems



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Advanced Computing Is an Key Enabler of Predictable, Reliability Microsystems



- Microsystems are complex
- Simulation using high performance computers are the key to
 - Systems that work right the first time
 - Systems that are ultra-reliable

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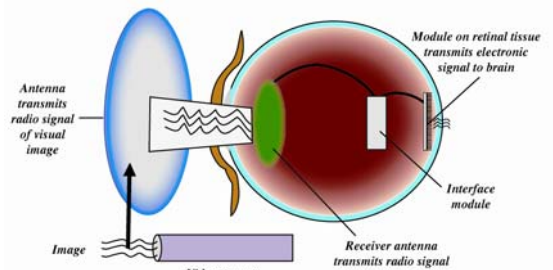
This is A “Disruptive Technology” The Landscape Is Being Changed Forever



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Curing Blindness: Intraocular Retinal Prosthesis (DOE Office of Biological & Environmental Research)



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Acknowledgements

*Many of the visuals shown
were generated
by the Microsystems Staff
at Sandia National Laboratories
In New Mexico and California.*

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For More Information



- MESA Program at Sandia
 - <http://www.sandia.gov/mesa/index.html>
- MESA Microsystems Learning Series
 - Feedback and information on future lectures: dellinta@sandia.gov

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